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SHORT COMMUNICATION

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The spiral of plants and soil in the cycle of life

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Abstract

This is not an article, but rather an account of a meeting that took place between two naturalists who had not seen each other for a few years and who freely exchanged their doubts and matured lines of thought. It is a provocative dialogue between the author of this article and Sandro Pignatti on natural evolution, considering the soil as a living matrix in which recycling of organic matter (including DNA) takes place. We can also interpret it as an attempt to merge the points of view of vegetation and soil ecologists, in order to revive the discussion on natural evolution. We think we understand it, but we don't. We discussed the following topics: 1) the relationship between phytosociology and plant ecology; 2) the soil as an individual or as an ecosystem's digestive machinery; 3) the hypothesis of a complemental geological (long-term) flow of DNA fragments in relation to the recycling process that takes place in the soil. Past and recent research in the fields of biology and evolution highlights a functional and primordial collaboration between living beings in the exploitation of natural resources. In this process that ultimately is life, soil plays a crucial role because it is cyclically and progressively renewed and enriches the sources of structural building blocks. The purpose of this story is to encourage us to reflect on the meaning of life, considering the functional contribution of death, which we perhaps mistakenly call "biodegradation".

Keywords

biodegradation, biodiversity, Castelporziano, DNA, natural evolution, humus, soil

He found me kneeling in front of a soil profile, 'How are you Zanella? What are you looking for… in a hole?'

I turned to see a jovial man; his eyes bright in the shadow of the visor of an American cap. December 6, 2010 was a sunny day in the Presidential Estate of Castelporziano (Rome).

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'Sandro Pignatti', he then pronounced, noticing the uncertainty in my gaze.

Beige waterproof jacket, a little shorter than Lieutenant Colombo's, suede boots, and blue cotton trousers with creases along the legs. I felt a surge of innate sympathy for him: my mother had never been able to understand that to iron blue jeans was not necessary.

Standing up and shaking his hand I said 'We met in 1991, at the Phytosociological Congress organized by Jean-Marie Géhu on forest dynamics, in Bailleul, France (Géhu 1993), do you remember?' Then, pointing to the soil profile I said: 'In the succession of horizons, this soil profile is a disaster'.

He nodded.

I was holding two soil samples (Fig. 1), an organic aggregate called the zoOH horizon (litter transformed into humus by soil animals; zo = zoogenic), and a glomerular handful of organo-mineral soil called the meA horizon (zoogenic organo-mineral aggregates; me = presence of meso-aggregates (1 < diameter ≤ 4 mm). 'Usually, these horizons are one on top of each other, but wild boars, using their nose like a plow, messed everything up; we will have to invent something to classify these strange cases...'.

He smiled as he touched the two samples, and added: 'It is always like this. You arrive on the field with clear ideas; then you observe the reality that surrounds you, and you are in the mist. Even worse, but challenging, when it starts to thin out,

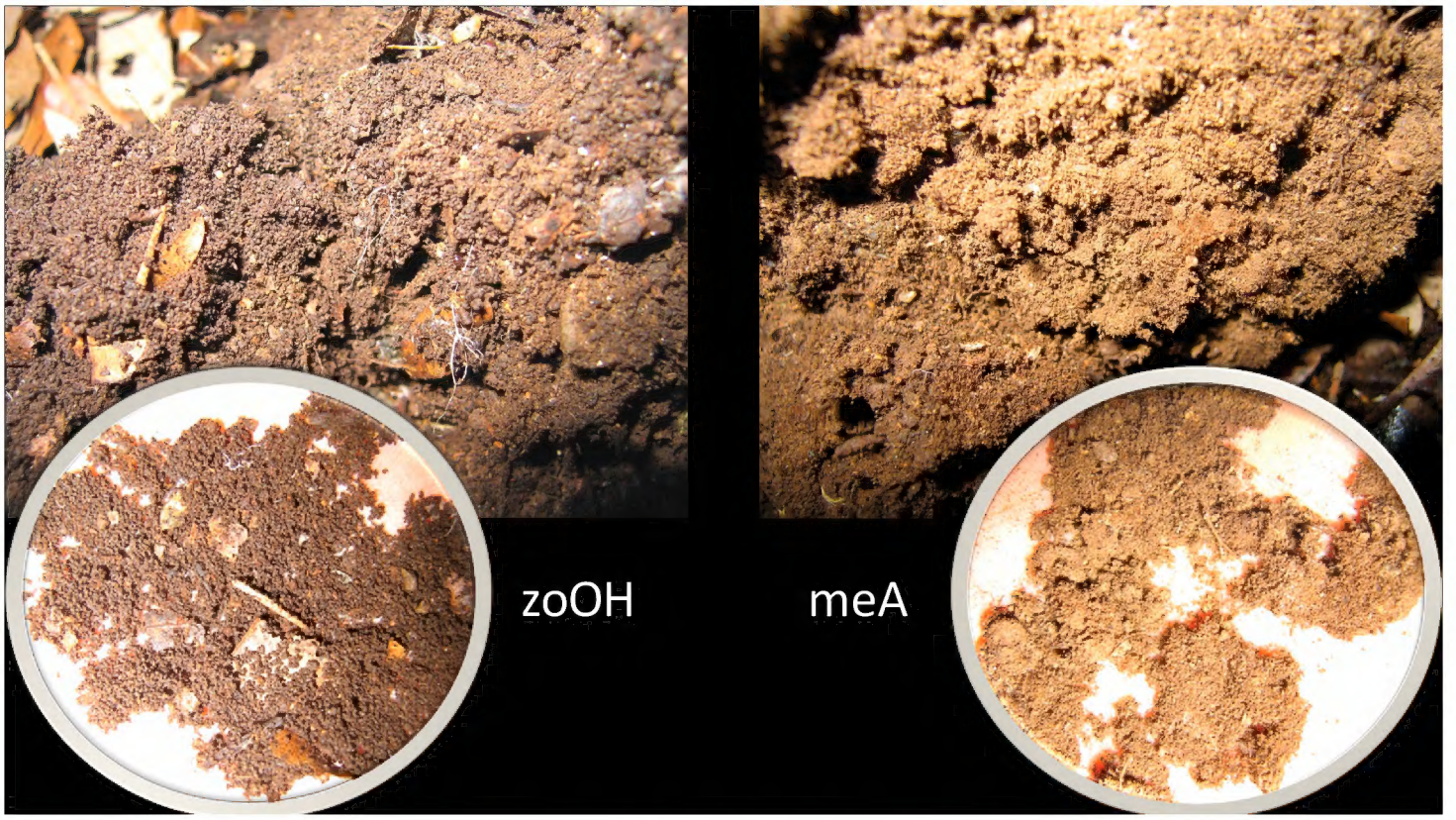


Figure 1. Left: zoOH, zo = zoogenic organic horizon, mainly originating from arthropods. This horizon is located at the soil surface below the more or less decomposed litter horizons and above a more mineral A horizon. Right: meA = organo-mineral A horizon originating from earthworms, whose feces are colonized by arthropods from the overlying horizon zoOH. "me" means horizon which has several stable aggregates with a diameter between 1 and 4 mm (made by earthworms). This meA horizon is typical of calcareous Mediterranean and sub-Mediterranean environments where arthropods and earthworms are called to coexist. The set of superficial horizons forms a humipedon called "Amphi" (Zanella et al. 2022), which means double, due to its double origin from arthropods and earthworms.

the road forks and you don't know which way is the right one. Did you sleep well in the villa?'.

'Not so well. There was a buxom lady in the room, who seemed to stare at me insistently. I pretended to turn off the light to sleep, and then immediately turned it on again to try to catch her moving... Nothing, still fixed on the painting, sly like a still too much alive Gioconda ghost. I also saw stars after bumping my bare foot against a heavy vase protruding from under the bed'.

'You were lucky! They gave you the royal room and you certainly kicked Vittorio Emanuele the Second's ceramic chamber pot', he said, accompanying this with a smile of cordial compassion... 'Let's go and see a forest area where the distribution of vegetation strictly depends on the characteristics of the soil; I want your opinion, follow me'.

We crossed a holm oak forest dotted with circular pools filled with shallow stagnant water, while carrying on an animated discussion about natural evolution. We started from the following empirical personal observations:

1) Mapping the phytosociological units of a plant landscape without using many unclassifiable gray areas is almost impossible. To draw the boundaries between phytosociological units in the field, characteristic plant species are used. However, by definition, these species have a narrow ecological range and are often absent along a line of demarcation between two units.

2) Due to the direct or indirect action of man, recent evolution has not been natural for at least a century. Theoretically, ecosystems should continue to evolve as if living beings and the environment forced these "volumes of nature" [trying to circumscribe Tansley's ecosystem concept (Tansley 1935)] to grow continuously into the future... In the final analysis, to realize this is "to live". For Tansley and many of us after him, the "indivisibility" of the ecosystem is of fundamental importance, although organisms may claim our primary interest. When we try to understand the essence of ecological functioning, we cannot separate living beings from each other, nor each living being from its own environment. If the future biological complexity and evolution remain unknown to us, we can nevertheless foresee them and confine them temporarily over a few decades.

3) Even if partially contradicting what we have just said about the cohesion of an ecosystem and considering plants separately (just as a thought), even if poorly defined on the territory, phytosociological units should exist. Evolving and changing, but composed of plants that "talk" to each other and co-evolve thanks to a common language. We can imagine this set of plants as located in a kind of black hole, influenced by ecological attractors (Mayr 1942) which change, because themselves dependent on the rest, in the space-time of a whirlwind of light, moving and indeterminate.

'I'm not a phytosociologist', he said, 'only an expert in vegetation ecology'.

'Even Lucio Susmel', I continued, 'wrote a well-documented essay against phytosociology (Susmel 1959). In the field, however, we are forced to imitate phytosociologists to recognize units within a landscape, using the colors and structure of the vegetation

as discriminating elements. In "I Boschi d'Italia" (Bartoli et al. 1998) you wrote that one must select those plant units that occupy an area "delimited by ecological factors". This principle was firmly emphasized by Jean-Marie Géhu, the spiritual heir of Josias Braun-Blanquet. On one hand, Jean-Marie feared the destruction of phytosociological classification by an excessive fragmentation of its branches; on the other, he was very fond of upward complexification, and developed the notion of functional unit of the landscape, very useful in cartographic operations (Bioret et al. 2021). We can't deny that vegetational units may be organized both in an ascending and descending way, while always exhibiting blurred outlines.

'I know', he went on, 'with Jean-Marie we discussed this aspect several times: when we (humans) do not understand a process, or when we face a new object, it is easier to coin a new word than to connect such a novelty to previous knowledge…'.

A few steps of silent reflection, and then '…when I could, I also took my family with me on excursions', he said this as if he were talking to himself, in a slightly lower tone of voice and closing his eyes with a sigh... 'However', with more impetus, 'I am absolutely convinced that plants communicate with each other, and also with animals. Simply to survive'.

'I learned that everything dies and ends up becoming humus', I added, 'cyclically. Pedofauna and microorganisms transform all this necromass into building blocks that can be used by new generations of living beings. We have two kinds of soil: a well-known one under plants, and a less visible one in the bellies of animals (even in our human belly), because animals also need to digest the collected food. I don't know to what extent DNA (along with everything else) is disassembled in a decomposition process that takes place in the soil under plants or inside animals, but...'.

'Interesting this double soil concept', he underlined. 'I have always thought that small pieces of DNA could reach new generations of living beings indirectly, outside of the reproductive pathway that we know. DNA exists outside cells, in the environment or stored in organic matter, like the words of a vocabulary of several successive generations; potentially, such a process could explain the observed co-evolution (Lovelock and Margulis 1974; Khakhina 1992; Sapp 1994), the non-coding DNA, and DNA that belongs to organisms other than the one that houses it (Ang 2021)'.

'How exciting!', I thought to myself. 'Not the sexually transmitted DNA, but also the one of a co-inhabiting community of living organisms, the whole ecosystem interacting with DNA, even the one flowing through the soil, in digestive and confined processes of death and recycling - at the ecosystem and individual scale (are the ones we call "mitosis" or "meiosis" original, miniature recycling processes?), a DNA that evolves and combines with the one sexually transmitted, and branches out within the limits imposed by the environment (and today more than ever by man), fluid, dynamic and unpredictable (Fig. 2)'.

Silence, and the rustle of boots in the forest litter.

'It is scientifically unusual to associate biodegradation and reproduction - I continued with less certainty in my words. However, when gametes fuse in a single $2n$ cell, they partially die. The question is: can reproduction be the result of a process of cell death? For example, a cell which swallows another, and which thus forms a new cell with $2n$ chromosomes. Afterwards, a $2n$ cell can give gametes, since functioning with n

chromosomes is already in its power. Decomposition and reproduction could then be linked, which, let's face it, is a bit like the process of death in the soil, which is necessary to provide the building materials for new life. Imagine a soil that perpetuates itself at a lower scale in what we call cellular metabolism and reproduction. When Miller and Urey (1959) tried to understand where life came from, they started from a soup that could also be interpreted as a primordial soil, or even a primordial cell'.

He stopped abruptly, turned to me and said: 'Yes, there is a thread that connects all living beings, and that still eludes us. A transmitted language that is made up of fragments of DNA. When the beaks of Darwin's finches come to mind, we don't give due importance to the joint evolution of plant seeds and insectivorous animals. But Darwin was so sure of the results of his observations that he put them in the title of his book: On the Origin of Species by Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life. In a formula, Natural Selection = Favoured races + Struggle of life. And just think that he found it without knowing anything about DNA'.

I added: 'Let's say that species evolve with a finality acquired on a higher scale, which is that of the ecosystem that contains them, and within a hierarchy of systems contained one in the other, from the cell to the universe. Of course, this "finality" remains in the future: when you get there, it changes. **It is not the species that evolve, but the ecosystems that contain them, with them**. Species alone don't go anywhere; they must co-exist, die and be recycled (Figure 2)'.

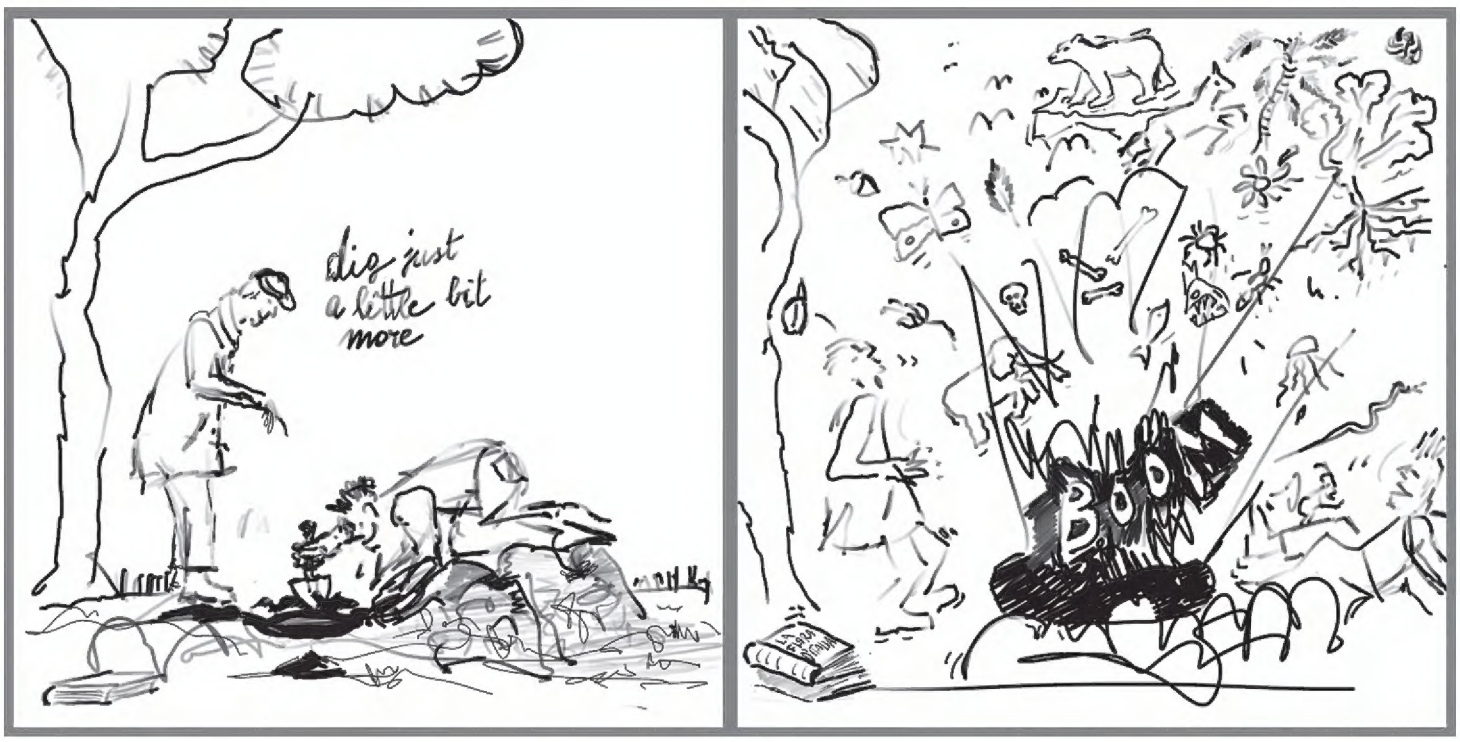


Figure 2. Evolution takes place in a kind of soil. Life and death belong to this same cyclical process which we call evolution; the first (production of new functional structures) needs the second (decomposition of old machinery, to recycle dead branches no longer adapted to the new present time and environment). The two phases must be able to occur at different scales, cyclically and continuously. At the beginning the building blocks were small systems (lumps of particles, then quarks); more recently the units of such material structures became complex, labile and malleable; this made them easier to use in "cells" of even more complex new systems. New systems grew to higher-scale and cyclically collapsed (major mass crises). All this still happens today. On Planet Earth, this process is more visible in the soil (or in soil-like processes), where life and death pass the baton.

Silently, we started walking through the woods again. Thinking.

There are published works demonstrating the action of parts of DNA in the soil, with important repercussions on biological evolution (Mazzoleni et al. 2015; Kooch et al. 2022; Zheng et al. 2022). Soil microorganisms of natural environments may have a lower biodiversity index, and be biologically and physiologically more connected to each other than those found in equivalent more anthropized environments (Mo et al. 2022, 2023). In a recent article, Klaes et al. (2023) show an organo-mineral aggregate of the A horizon of an Andosol magnified to the micrometric scale and explain its functioning with graphs that speak for themselves: the flows of minerals and organic matter are interdependent and connected to the biological activity which varies with the rainy periods. Each aggregate is a miniature soil. Presented in preprint (Martins et al. 2023), the microbial biodiversity outside and inside the soil would be functionally connected; nitrogen fertilization significantly reduced soil bacterial diversity (–2.3%), and this effect was more significant in cropland than grassland and forest (Wang et al. 2023). Polyspecific meadows make better use of environmental resources than monospecific ones (Moeneclaey et al. 2022). An exogenous species can generate a new ecosystem (Gentili et al. 2022). The process can also be purposely designed to build up what needs to be destroyed, leaving behind only what is needed to continue in the right direction (Ameisen 1999). Like other species, *Homo sapiens* may be just a link in the chain.

Living beings are organized into functional groups, they are not randomly aggregated, but each of them must serve as a cog in a clock system (Ette et al. 2023; Fan et al. 2023; Liu et al. 2023; Lopezosa et al. 2023; Martins et al. 2023; Zhang et al. 2023; Zhu et al. 2023). Thus, they constitute members of a functionally biodiverse species, which interact and together "give transformed resources to others in order to also receive modified resources from others". Bringing different species together without them being functionally connected increases biodiversity and automatically generates a new system. This, however, if allowed to evolve, tends to return to a status with functionally connected biodiversity. When we destroy a natural ecosystem, we eliminate with it this historical set of biological, physical-chemical interdependences that is unknown and for this reason difficult to reconstruct. These aspects certainly recall the very important pioneering works of Lovelock and Margulis (1974), Lovelock (1990), Margulis (1998).

Three attempts to graphically summarize all these thoughts, also with the help of Artificial Intelligence, are shown in Fig. 3.

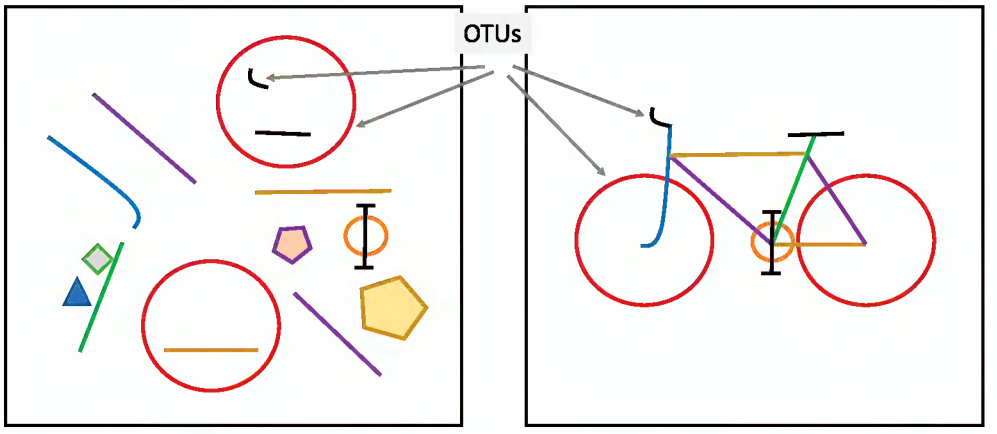
We arrived at the site of the Castelporziano estate where the forest changed from ash wood with laurel (*Laurus nobilis* L.) on fresh soil, to oak wood with Turkey (*Quercus cerris* L.) and Frainetto (*Quercus frainetto* Ten.) oaks on drier and filtering soil. The passage materialized along a band that meandered between the two types of forest. We dug holes: the ash wood grew on a Mull (without OH horizon) resting on an impermeable clay layer (Bt horizon), while in the oak wood we found

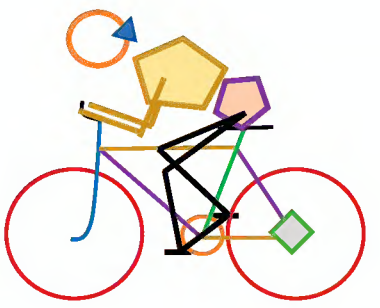
B

Albarella
Anthropized ecosystems
(higher indices of microbial diversity)

Caleri
Natural ecosystems
(lower indices of microbial diversity)

On the road
Functional anthropized ecosystems
(high and functional biodiversity)





Artificial ecosystems (like a bed of exotic flowers) are dependent on human restoration. They tend to disappear or change radically if left to free evolution, as if the missing interdependence between the components had to be compensated by the external intervention of man.

Ecosystems that coevolve into a whole that maintains functionality. On the vegetation map shown above, one can observe the materialization of this concept in the arrangement of natural vegetation in regular bands along a gradient that depends on the distance from the sea, in stark contrast to the landscape of Albarella.

Do you like biking?

Figure 3. Scrutinizing evolution **A** comparison of vegetation maps; on the left the vegetation bands of the protected coastal area of Porto Caleri; on the right the relict or transformed patches of the same vegetation in the inhabited area of Albarella. The codes on the maps correspond to survey points. When vegetation grows freely, it is arranged along natural gradients which indicate the dependence of living organisms on the environment in which they grow **B** high biodiversity is not synonymous with high functionality. In Porto Caleri, a natural area, there were fewer taxonomic units among soil microorganisms than in the equivalent neighbouring anthropized ecosystem of Albarella. When humans change the environment decisively, they trigger a new evolutionary dynamic. The problem is that we don't know where this new dynamic will lead (with a thought to the ongoing global warming).

C
Origin of life, death, DNA, soil, evolution, colourful, mist
Origin of life, death, DNA, plant and soil, evolution, colourful, impressionist

Figure 3. Continued. **C** The two figures are produced in a few seconds by an online A.I. software (https://www.bing.com/images/create), using as prompt the words written under the pictures.

an Amphi (with OH horizon above an A horizon), in contact with a sandy and filtering horizon (BC). The ecosystem changed altogether, in just a few meters.

While we were eating a sandwich at the end of the excursion, I also asked him 'How did you manage to put together the Flora of Italy (Pignatti et al. 2017b, 2017a, 2018, 2019)?'.

'My house was full of lists of plants', he answered frankly. 'In small notebooks scattered on the bedside table, along the stairs, on each bookshelf, everywhere. Census years. And a network of passionate and hard-working collaborators. Indeed, it amused me, it has been my life. I can't tell you what a struggle it was to put everything in order. A monstrous effort, and we're not done yet'.

Smiling, like a hero.

Author Contributions

The author only added references to the dialogue he remembers, to simulate the style of a scientific communication.

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